

Chapter 2 Median Barrier Effectiveness

While no barrier can eliminate the consequences for every driver who runs off the road, adding median barrier is expected to reduce the number of vehicles that cross a median and enter oncoming traffic. Median barrier is also an object that an errant vehicle may hit. As a result, barrier is designed to minimize the forces on occupants in vehicles that hit the barrier and provide some capacity to redirect the vehicle in a controlled manner or bring the vehicle to a controlled stop.

1 Are median barriers effective?

A WSDOT report in March 2002 summarized a study to determine if more median barrier should be used on freeways in Washington State. The study concluded that where median width was 50 feet or less, median barrier should be installed when a new road project is underway in the area. The barrier would add to the crossover protection provided by the width of the median itself. WSDOT adopted this policy. National guidance, by contrast, is somewhat less protective in that it recommends an evaluation for the need for barrier when the median width is 30 feet or less.

A November 2003 study of the effectiveness of cable median barrier found that after the installation of a cable barrier the number and severity of cross median crashes was significantly reduced. We reviewed collision data for approximately 26.5 miles of I-5 including cable median barrier in Vancouver, Fife and Marysville. On an annual basis the number of median crossover crashes was reduced from sixteen to approximately four and the number of fatal and disabling crashes in the median was reduced from 6.6 to approximately 2.0. Subsequently, WSDOT pursued median barrier installation in all freeways regardless if other construction was planned.

2 How do different types of median barrier perform on Washington State highways?

To assess the relative effectiveness of different types of median barriers, WSDOT engineers analyzed 11,457 median barrier collisions that occurred on Washington State highways between 1999 through 2004. These collisions were identified as incidents where a barrier was either the first or second object that was struck. This six year period represents the most recent highway collision data available.

The comparison of the different barriers' performance did not include I-5 in Marysville because this cable barrier section is performing differently than other sections around the state. (See Chapter 1 for more information on the performance of cable barrier on I-5 in Marysville.)

Minimizing injuries and death

The percentage of median crashes that result in injury or death is significantly lower for cable barrier (16%, not including I-5 in Marysville) than for concrete barrier (41%) or W-beam guardrail (41%). The percentage of disabling and fatal crashes, the least frequent but most serious type of crash, is lowest for concrete barrier (2.1%) followed by cable barrier (2.6%) and beam guardrail (4.4%).

Exhibit 2-1

Barrier Performance: Injury Severity

Barrier type	Total number of collisions	Injury severity					
		Not stated	No injury	Possible injury	Evident injury	Disabling injury	Fatal
Concrete barrier	7,585	114 (1.5%)	4,345 (57.3%)	1,901 (25.1%)	1,061 (14.0%)	130 (1.7%)	34 (0.4%)
W-beam guardrail	2,579	52 (2.0%)	1,468 (56.9%)	532 (20.6%)	412 (16.0%)	73 (2.8%)	42 (1.6%)
Cable, without I-5 Marysville	152	6 (3.9%)	121 (79.6%)	14 (9.2%)	7 (4.6%)	4 (2.6%)	0 (0%)
Cable, with I-5 Marysville	171	3 (1.8%)	132 (77.2%)	11 (6.4%)	17 (9.9%)	3 (1.8%)	3 (1.8%)
All cable barrier	323	9 (2.8%)	253 (78.3%)	25 (7.7%)	24 (7.4%)	7 (2.2%)	5 (1.5%)
Bridge rail	970	14 (1.4%)	608 (62.7%)	197 (20.3%)	126 (13.0%)	21 (2.2%)	4 (0.4%)
Total	11,457	189 (1.6%)	6,674 (58.3%)	2,655 (23.2%)	1,623 (14.2%)	231 (2.0%)	85 (0.7%)

Washington State Highways, 1999-2004

As the chart below shows, collisions with cable barrier (not including I-5 in Marysville) are significantly less likely to involve multiple vehicles than guardrail and concrete barrier.

Exhibit 2-2

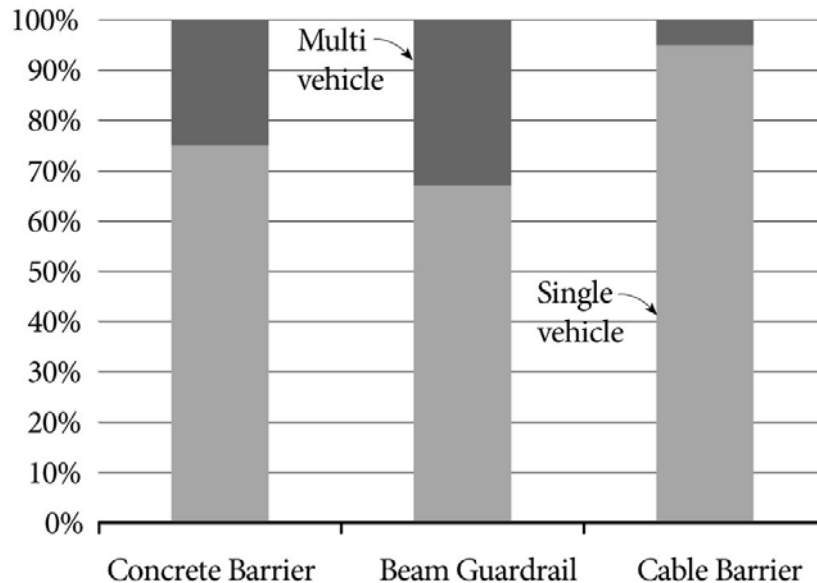
Single and Multi-Vehicle Collisions

Exhibit 2-3
Average Number of Injuries and Fatalities Per Collision

	Concrete Barrier	Beam Guardrail	Cable Barrier
Single vehicle collisions	0.47	0.45	0.19
Multi-vehicle collisions	0.81	0.89	0.88

Washington State Highways, 1999-2004, cable barrier data does not include I-5 Marysville

Less than half as many injuries and fatalities per collision occur when a single vehicle collides with a cable barrier compared to concrete barrier or guardrail. When multiple vehicles are involved in a collision the injury rate increases for all barrier types, and is comparable.

Head on collisions

The most damaging and deadly crashes are those that involve vehicles colliding head on. These occasionally occur when a vehicle goes beyond a median barrier. Overall, one percent of errant vehicles that hit concrete barrier go beyond the barrier, compared to beam guardrail (4%) or cable barrier (5%, not including I-5 in Marysville).

Rollovers

Injuries can be more severe when vehicles roll over during a collision. Like all types of median barrier, the reported percentage of disabling and fatal crashes with cable barrier is heavily influenced by rollover collisions. For cable barrier collisions outside of the Marysville area, where disabling or fatal injuries were reported, the errant vehicle rolled over in three of the four collisions. It is unclear if the barrier contributed to the rollover or if the vehicle was likely to roll over regardless.

What happens when motorcycles collide with median barrier?

We analyzed collisions that involve motorcycles hitting median barriers. Motorcyclists are relatively unprotected.

Motorcycles don't have many of the safety features that are found on cars such as seat belts and airbags. This makes motorcycle travel riskier than automobile travel. Consequently the injury rate when motorcycles hit barrier is much higher than the rate when automobiles hit barrier. We found that, regardless of what type of median barrier motorcyclists struck, there was no significant difference in injury severity.

We evaluated motorcycle collisions for 2003 and 2004. We only evaluated collisions where the first object struck was a barrier. We didn't evaluate collisions where the barrier was the second object struck because it wasn't possible to discern whether injuries resulted from the primary collision or the secondary collision. Cable barrier is not listed in the chart because it wasn't the first object struck in motorcycle collisions during the past five years. There is one instance where a motorcycle experienced a secondary collision with a cable barrier. Only minor injuries resulted and it is not clear whether the motorcyclist sustained the injuries from the initial collision or the collision with the cable barrier.

For this analysis the location of the barrier may have been on the roadside or the median. One hundred fifteen motorcycle collisions were evaluated for injuries and fatalities. Of these 115 collisions, 40 struck a concrete barrier, 65 struck W-beam guardrail and 10 struck a bridge rail.

Exhibit 2-4 Barrier Performance, Motorcycles

Barrier Type	Collisions		
	Total Collisions	Percent Injury Collisions	Percent Fatal Collisions
Concrete Barrier	40	85%	7.5%
Beam Guardrail	65	81.5%	9.2%
Bridge Rail	10	80%	10%

Washington State Highways, 2003-2004

3 What have crash tests revealed about median barrier effectiveness?

All barriers WSDOT uses have been crash tested and have met National Cooperative Highway Research Program (NCHRP) Report 350 criteria that specify that "...the vehicle should not penetrate, underide or override the installation, although controlled lateral deflection of the test article is acceptable."

The NCHRP was created in 1962 to conduct research in acute problem areas that affect highway planning, design, construction, operation and maintenance nationwide. It is sponsored by the American Association of State Highway and Transportation Officials (AASHTO), WSDOT and other state departments of transportation, and in cooperation with the Federal Highway Administration (FHWA).

NCHRP Report 350 identifies crash-testing criteria for roadside features that are to be placed along the highway. Following these national standards, the tests listed below involved a small car and/or standard pickup truck hitting the barrier at 62 miles per hour (mph) on level ground in a controlled crash test environment. Crash test measures include:

- **occupant impact velocity**, which measures the force on vehicle occupants when the vehicle collides with the barrier. A lower velocity is better because it reduces the risk of injury.
- **ridedown acceleration**, which measures how abruptly a barrier stops a vehicle. A lower acceleration rate is better because it means that the barrier stops a vehicle in a more controlled manner, reducing the impact on vehicle occupants and reducing the risk that the vehicle will bounce back into traffic.

- **deflection**, which measures how much a barrier moves when it's hit by a vehicle. Some types of barrier are rigid while others are designed to flex when struck by an errant vehicle. More flexibility generally results in fewer injuries because it reduces the forces on the people inside the vehicle. However deflection requires additional room on the highway, because the object the barrier is shielding must be outside the deflection distance.

Figure 2-5
Barrier Performance Measurements

Barrier System	Occupant Impact Velocity (m/s)	Ridedown Acceleration (g's)	Deflection (feet)
	NCHRP 350 max – 12 m/s	NCHRP 350 max – 20 g's	
Cable	4.1	3.9	11.2
High tension	3.9	8.6	9
W-beam guardrail	7.0	12.9	2.7
Precast concrete	5.6	7.1	4.6
Jersey shape rigid concrete	6.0	13.9	0
Slope shape rigid concrete	8.4	15.3	0

Cable barrier (generic system)

WSDOT tested cable median barrier (generic system) in which both a pickup truck and car were brought to a controlled stop. The cable barrier kept all of the test vehicles from passing through, over or under the barrier. The occupant impact velocity was significantly lower than other types of barrier. Less force and deceleration generally results in fewer injuries to occupants. The deflection was significantly more than other barrier, which limits the use of this type of barrier to areas where there is adequate space.

W-beam guardrail

Crash tests included in a February 14, 2000 memo from FHWA on Nonproprietary Guardrails and Median Barriers indicate that W-beam guardrail successfully kept the test vehicle from passing through, over or under the barrier. The relatively high occupant impact velocity and ridedown acceleration indicate that W-beam guardrail controls collisions more abruptly than other types of barrier, which transfer more force to vehicle occupants and increase the likelihood that the vehicle will rebound into traffic. Deflection was slight, which means this type of barrier can be used in areas where there is little space.

Precast concrete barrier

Type 2 concrete barrier, precast concrete barrier in the New Jersey shape, has been in use in Washington State since the 1970s. In 2001 WSDOT sponsored a crash test of this barrier involving a pick-up truck. We only performed the truck test because successful small car tests were previously completed on similar precast barriers and we were concerned about the affect of a heavier vehicle on the connectors between precast concrete barrier segments. The barrier prevented the test truck from passing through, over or under the barrier and successfully redirected the truck. The occupant impact velocity and ridedown acceleration indicate that this barrier offers a more controlled collision and reduced affect on vehicle occupants than more rigid barriers, though there is a notable disadvantage when compared to cable barrier. Deflection was modest, which means this type of barrier can be used in areas where there's limited space.

Rigid concrete barrier – Jersey shape

Crash tests included in the February 14, 2000 memo from FHWA on Nonproprietary Guardrails and Median Barriers indicate that rigid concrete barrier in the Jersey shape successfully kept the test vehicle from passing through, over or under the barrier and successfully redirected the vehicle. The relatively high-occupant impact velocity and ridedown acceleration indicate that this type of rigid concrete barrier controls collisions more abruptly than other types of barrier, which transfers more force to vehicle occupants and increases the likelihood that the vehicle will rebound back into traffic. No deflection was observed, which means this type of barrier can be used in areas where there is very limited space.

Rigid concrete barrier – single slope shape

Crash tests included in the February 14, 2000 memo from FHWA on Nonproprietary Guardrails and Median Barriers indicate that rigid concrete barrier in the single slope shape successfully kept the test vehicle from passing through, over or under the barrier and successfully redirected the vehicle. The relatively high-occupant impact velocity and ridedown acceleration indicate that this type of rigid concrete barrier controls collisions more abruptly than other types of barrier, which transfers more force to vehicle occupants and increases the likelihood that the vehicle will rebound into traffic. No deflection was observed, which means this type of barrier can be used in areas where there is very limited space.

High tension cable barrier

Recently there have been several proprietary cable barrier systems developed using a high tension cable system, which results in reduced deflection. WSDOT began using these systems in 2004. In tests, high tension barrier brought vehicles to a stop faster than generic cable, yet exerted less force on occupants. In addition to the reduced deflection distance, these systems may cost less to maintain.

4 What have crash tests revealed about beam guardrail and cable median barrier on slopes?

The body of knowledge about median barrier performance on slopes is limited because median barrier tests are usually conducted on level ground. However, limited tests of barrier performance on slopes were conducted and led to our current guidelines. A national study of barrier performance on slopes was recently funded. When complete, the information will provide further guidance on placement of median barriers on slopes.

A slope ratio indicates steepness, one of the most important slope characteristics. For example, a slope ratio of 6H:1V indicates that for every six feet of horizontal distance the elevation changes one foot vertically.

Beam guardrail and cable barrier have been tested on 6H:1V slopes. The tests indicate that when a vehicle leaves the roadway onto a slope of 6H:1V or steeper, the bumper may be higher than normal until the vehicle's suspension reacts.

Crash tests examined vehicles striking guardrail on a 6H:1V slope placed closer than 12 feet from the slope break. In these tests, vehicles hit the rail higher than normal and passed over the guardrail.

Crash tests revealed that it is appropriate to place cable barrier anywhere on a 6H:1V slope and that it is not recommended to place concrete barrier on slopes steeper than 10H:1V.

What happens when cable barrier is placed beyond the bottom of the slope?

Some additional testing on cable barrier was conducted by the Federal Highway Administration (FHWA) in April 2004. In these tests, the barrier was installed in a ditch section with 6H:1V slopes so that the vehicle would pass over the bottom of a ditch before hitting the barrier. This research found that the cable median barrier performs as designed when placed within 1 foot of the bottom of the ditch. However, when placed four feet up from the bottom of the ditch some vehicles may have a potential to go under the cables. This occurs because the front of the vehicle overhangs the front tire; the front of a vehicle traveling through a depressed median does not stop its downward decent until after the front tire has reached the low point and the suspension begins to rebound.

One month following the FHWA tests, in May 2004, WSDOT issued directions to avoid this type of placement in new projects pending final guidance from the American Association of State Highway and Transportation Officials (AASHTO) and FHWA. That direction stated, "Avoid installing cable barrier within 1' to 6' offset of the ditch centerline." The FHWA did not require or recommend that states move existing cable barrier or change cable barrier placement in new projects. AASHTO is now finalizing guidance on cable barrier placement in depressed medians. It is anticipated that their guidance will recommend avoiding the area between 1 foot and 8 feet away from the low point of the ditch.

Exhibit 2-6

Car Lifting Cable Barrier



This photo, from a 2004 Federal Highway Administration crash test, shows how the front tires of a sedan compress after hitting the bottom of a ditch. This allows the bumper of the car to nudge under the lowest barrier cable.



As the vehicle continues forward it lifts the cable median barrier and continues up the slope as the cables pass over the top of the vehicle.

5 What crash test criteria were used and why were they selected?

The NCHRP Report 350 identifies crash-testing criteria for roadside features that are to be placed along the highway. The criteria specify a number of conditions including:

- number and type of tests for different roadside features
- vehicle type and mass
- test speed and angle of impact
- impact location
- evaluation guidelines

Test Level 3 (TL3) is the basic level for performing crash tests of median barrier on freeways (longitudinal barriers on high-speed facilities). The standard test criteria for TL3 barrier systems include crash testing with two vehicle sizes, a small car and a pickup truck.

A pickup truck is used to evaluate the barrier's ability to restrain and redirect the impacting vehicle. This test focuses on the interaction between the mass of the vehicle and the internal strength of the barrier. Another test uses a small car and looks primarily at impact forces transferred to the occupants as well as restraint and redirection. Barrier systems that pass tests with both a small car and a pickup truck provide a balance between barrier penetrations and injuries incurred during the collision with the barrier.

What is the worst practical condition philosophy and why is it followed for crash tests?

The criteria specified in NCHRP Report 350 were developed based on a worst practical condition philosophy. This philosophy recognizes that there are an unlimited number of vehicle types, speeds, approach angles and site conditions that can be involved in crashes. It is not practical to test every type of barrier for every combination of these variables. As a result, we evaluate barriers for very severe conditions within practical limits.

We limit our tests and reduce the number of conditions to keep the evaluation within economic and practical bounds. For example, to retain a semi-truck at 70 mph at a large impact angle might require a thick rigid concrete barrier that is 8 feet tall. We know that this type of barrier would exert forces in excess of acceptable limits on a small car. In addition, requiring this type of barrier along all of our freeways would not be practical and would have significant effects on communities, the environment, budgets and more. As a result, we have not conducted tests involving semi-trucks at 70 mph and at a large impact angle.

What speeds are used for crash tests?

The NCHRP Report 350 criteria establish the speeds at which crash tests are conducted. This report is considered a national standard that has been adopted by the FHWA. The highest speed used for testing is 100 kilometers per hour (approximately 62 mph). In 1962 high speed tests were conducted at 60 mph. The speed was increased to 62 mph when testing criteria were converted to metric.

In April, 1996 the FHWA indicated that though posted speeds were being increased, they continued to endorse the 100 kilometer per hour speed for high speed crash tests. FHWA acknowledged that the test procedures are not strictly tied to speed limits. FHWA also acknowledged that the 60 mph test speed was established when most states had legal speed limits higher than 60 mph.

While the use of a test speed that is less than the posted speed may seem incongruous, it is important to remember that in many cases the driver of the vehicle may be braking prior to impact. In addition, vehicle design improvements have made them more crashworthy.

Why doesn't WSDOT test barriers at higher speeds?

The federal government, other states and WSDOT have not invested in testing at higher speeds because less than 2 percent of all crashes exceed the speed and impact angle used in tests. An increase in the test speed or change in vehicle type would affect the performance of all barriers WSDOT installs. Beam guardrail, precast concrete, rigid concrete and cable barrier systems are likely to exhibit periodic failures with increases in crash speeds or impact angles that are at the outer edges of the actual circumstances in which the barriers are anticipated to perform. This criteria for crash testing has served to identify barrier systems that have performed as designed in a wide range of different barrier placements and in the preponderance of off road collisions.